Australian Government
Department of Defence
Defence Science and Technology Organisation

Roll Damping Characterisation Program: User Guide

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DSTO-GD-0830

ABSTRACT

The Roll Damping Characterisation Program (RDCP) used by the Defence Science and Technology Organisation (DSTO) is an efficient and effective means to characterise and quantify the roll damping characteristic of a free-floating maritime platform. The program uses roll decay trial data in conjunction with a simple numerical optimisation routine and the Fourth Order Runge-Kutta integration method to determine the platform's linear and non-linear roll damping coefficient terms. These coefficient terms are integral to conducting accurate numerical simulations of maritime platforms in support of the Australian Defence Organisation's capability acquisition programs and the Royal Australian Navy's in-theatre operations and through-life capability management. This report provides detailed operational guidance notes to support the application and use of the RDCP.

Published by

Maritime Division
DSTO Defence Science and Technology Organisation
506 Lorimer St
Fishermans Bend, Victoria 3207 Australia

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Fax: (03) 9626 7999

June 2014

APPROVED FOR PUBLIC RELEASE

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Executive Summary

Numerical ship motion simulation and analysis tools provide an efficient and effective means to determine and evaluate the motion performance of a maritime platform operating in a seaway. Notwithstanding this, many of the numerical simulation tools are based on potential flow theory and are therefore unable to numerically model the non-linear viscous roll damping effects that influence a platform's roll motion response. Without an accurate damping model and coefficient set, the simulated motion response can be in significant error. While several empirical methods exist to estimate the viscous roll damping component, these methods are limited to specific hull form types and geometries. Where necessary, it is common practice to conduct model or full scale trials to measure and characterise the roll damping component of a hull form. This is normally done by conducting a free-roll decay or sallying test.

The Defence Science and Technology Organisation (DSTO) have developed a software-based tool called the Roll Damping Characterisation Program (RDCP) to process model and full scale roll motion test data and characterise and quantify a platform's roll damping response. The program reads test condition and time-series roll motion data from experiments and uses a numerical optimisation method in conjunction with the fourth order Runge-Kutta integration method to solve the second-order differential equation of roll motion. The program returns the linear, quadratic and cubic damping coefficient terms associated with the common permutations of the non-linear damping equation. In addition to this, RDCP provides a quantitative evaluation of the best fit damping equation (collection of the linear and non-linear terms).

The RCDP is suitable for processing and analysing full scale and model scale data for any floating platform (surface ship, submarine, landing craft or off-shore structure) that possesses a linear or non-linear roll damping characteristic.

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Contents

Abbreviations and Acronyms

DSTO	Defence Science and Technology Organisation
MCR	Matlab Compiler Runtime
RDCP	Roll Damping Characterisation Program

Nomenclature

B	Beam overall
b^{cub}	Cubic roll damping coefficient
b^{lin}	Linear roll damping coefficient
b^{qua}	Quadratic roll damping coefficient
C_{xx}	Roll restoring moment coefficient
g	Gravitational acceleration (constant = 9.81 m/s^2)
GM_T	Transverse metacentric height
I'_{xx}	Roll inertia moment coefficient
k'_{xx}	Virtual roll gyradius
KG	Height of the vertical centre of gravity above the keel datum
KM_T	Height of the transverse metacentre above the keel datum
R^2	Coefficient of determination
T	Time
$T_{\phi Ave}$	Average roll period
T_{MS}	Draft at midships
T_{ϕ}	Natural roll period
Δ	Mass displacement of the platform
τ	Trim angle (+ve by the stern)
ϕ	Roll angle (superscript dots represent time derivatives)
ω_{AVE}	Average roll frequency
ω_{ϕ}	Natural roll frequency

1. Introduction

This document outlines the requirement for and development and use of a software program (the Program) developed by the Defence Science and Technology Organisation's Maritime Division to enable the analysis and characterisation of surface platform roll motion characteristics. The Program provides a direct method of analysing experimental and full scale roll decay test data to determine the linear and non-linear damping coefficient terms used in the calm water roll equation of motion (Equation 1). In this formulation the restoring moment is considered to be linear.

$$I'_{xx}\ddot{\phi} + \left(b^{lin} + b^{qua}\left|\dot{\phi}\right| + b^{cub}\dot{\phi}^{2} \right)\dot{\phi} + C_{xx}\phi = 0 \qquad \text{Equation 1}$$

The overarching requirement for the Program comes from the need to directly analyse experimental or full scale trial roll decay test data to determine the appropriate damping formulation and the associated linear and/or non-linear damping coefficients. The damping model and coefficients are required for use in numerical ship motion prediction programs to accurately simulate the roll motion response of a floating platform.

2. Background

2.1 Ship Motion Prediction

The use of numerical ship motion prediction programs to model and simulate the motion response of a ship or submarine operating in a seaway is a standard approach to investigate platform performance and operability limits. While such programs have been shown to provide results that are in good agreement with experimental and/or full scale trial data, it is still not a trivial process to accurately model the roll motion. This is largely due to the non-linear roll motion characteristics experienced by some hull types. To account for the effects of damping it is common to use a roll damping factor or a set of damping coefficients as inputs into the software program.

There are currently three approaches that can be used to determine platform specific damping parameters:

1. Measurement and analysis by experiment or trial
2. Calculation using an empirical method (where available)
3. Simulation and calculation using advanced computational methods

Despite continued efforts to improve these methods, there are still limitations associated with each type. Despite this, the use of an experiment or a full scale trial (where practical) is considered to be the most appropriate method for application to any platform type.

2.2 Roll Damping Modelling

There are several sources that contribute to the physical roll damping effect. Among these is skin friction, eddy shedding and wave-making. The damping sources and their contribution will vary depending on the platform and its operating condition. Nonetheless, the damping effects have been classified as being linear or non-linear in nature. A concise discussion of the physical phenomena that act to dampen roll motion is presented by Himeno [1]. These physical damping effects are modelled in the Program using the series expansion shown in Equation 1. The common arrangements of the formulation are: linear only, linear and quadratic, and linear and cubic. These formulations have been found to adequately model the roll damping characteristics of many platform types. However, it is important to understand that the model is only a mathematical representation of the physical phenomenon. Dalzell [2] postulates that in fact the linear and quadratic and linear and cubic forms of the damping model are merely of equivalent value as both account for non-linearity and are only representations.

3. Program Overview

3.1 Scope of Application

The Program has been developed to enable the analysis of roll decay test data measured and recorded during a model scale roll decay test or a full scale roll decay (sallying) test. The Program can be used for any surfaced platform including, but not limited to, the following:

1. Monohull and multi-hull surface ships
2. Submarines
3. Barges and pontoons

It is expected that the Program outputs will be used to guide the analyst with respect to the roll damping characteristic of the platform under consideration and as inputs for numerical ship motion prediction software tools.

3.2 Description of the Program

The Program source code was written using MATLAB V.2012b [3] and compiled as a standalone executable application (Roll Damping Characterisation Program or RDCP). The Program comprises three fundamental components:

1. Test data input
2. Data analysis and computation
3. Results data output

The Program is operated by running each of the components in succession as indicated in the process flow diagram shown in Figure 1. The core processing component of the Program (Data analysis and computation) uses a fourth order Runge-Kutta method to simulate the response of the user input roll decay test. The simulation uses the calculated inertia and restoring moment coefficient data and the initial roll angle (determined from the input test data) as the initial conditions and solves for the nominated damping coefficients using a standard MATLAB optimisation routine. The optimisation routine determines the unique damping coefficient values that provide the best correlation between the simulated and corresponding experimental responses. The data analysis and computation component returns the damping coefficient data and a measure of correlation (coefficient of determination) for the following damping models:

1. Linear only
2. Linear and Quadratic
3. Quadratic only
4. Linear and Cubic
5. Cubic only

The five formulations simulated by the Program have been selected as they comprise the three principal forms discussed in Section 2.2 and the two non-linear only models (quadratic only and cubic only). The damping coefficient values returned by the Program for the five simulations can be compared amongst one another to gain further insight into the type of damping that is dominant within the system: linear or non-linear.

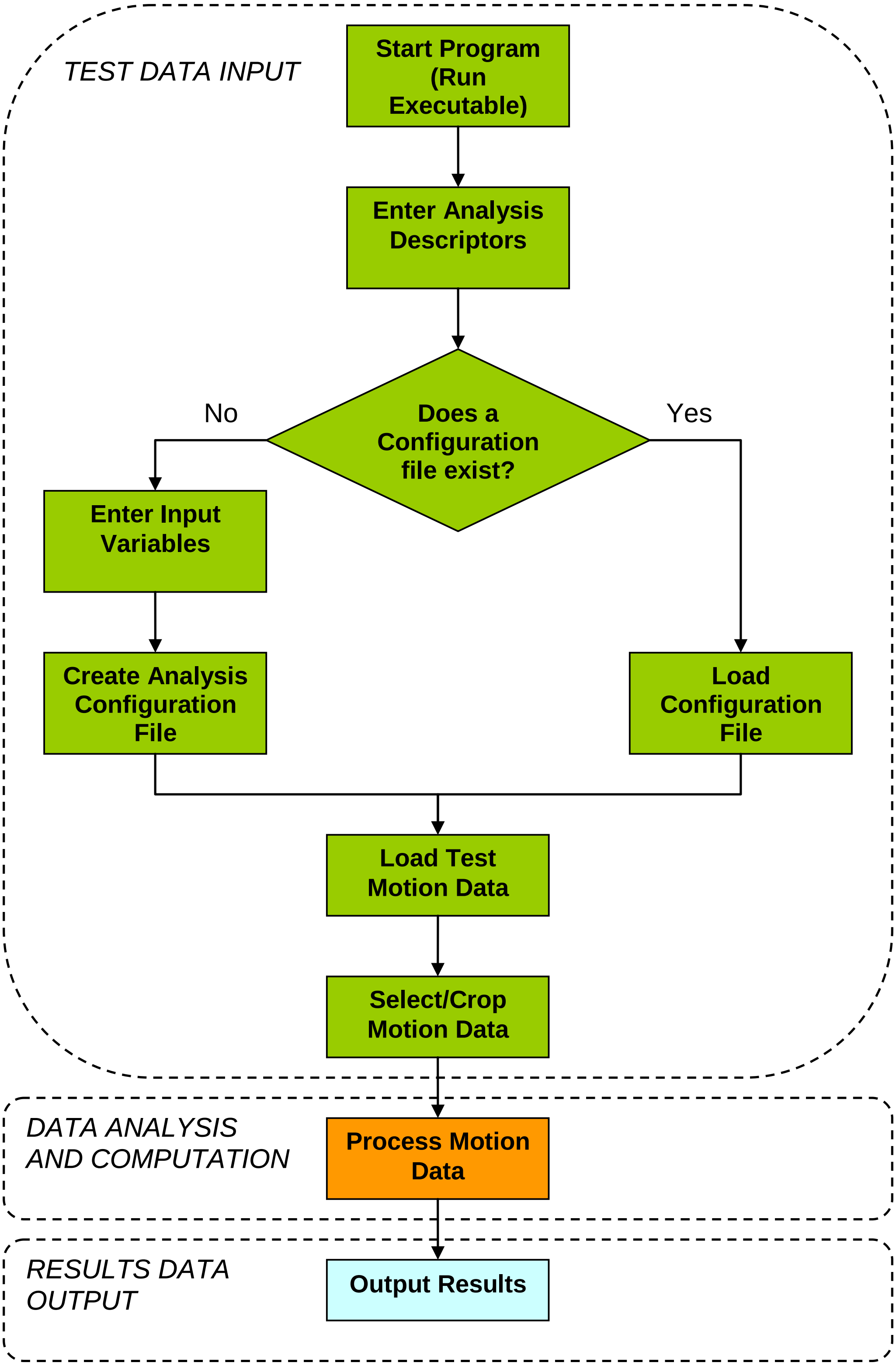

Figure 1 Program process flow diagram

3.3 Calculation and Analysis Assumptions

The simulation and optimisation algorithm is based on the following assumptions:

1. The user input roll decay test data (roll amplitude versus time) commences at the apex of a local roll maximum or minimum. The Program is designed to assist the user in cropping the Motion Data File data domain so that it commences at the local maximum or minimum.
2. All calculated damping coefficient values returned by the Program are negative in sign.
3. The analysis process assumes that the initial test conditions comprised calm water with no wind and that the platform is unconstrained and free to oscillate in roll.
4. The Program uses a linear restoring coefficient and is therefore only applicable for roll angles up to 20 degrees [4].

4. Program Data Artefacts

4.1 File Protocol

The input and output files and their file type are listed in Table 1 below.

Table 1 Program files and file types

File Type	File Extension	Description
Configuration	*.xls	A Microsoft Excel file that contains two columns of data. The first column contains the input parameter names. The second column contains the input parameter values. An example is shown in Figure 5.
Motion Data	*.xls	A Microsoft Excel file that contains two columns of data. The first column contains the time stamp data. The second column contains the roll amplitude data. An example is shown in Figure 10.
Output Data	*.xls	A Microsoft Excel file that contains four worksheets. The worksheets contain the user input data, calculated data, roll damping analysis results data, test and simulation roll decay motion response data and the roll period data. Further detail is provided in Section 4.2.3.
Output Figure	*.fig	A MATLAB figure file that contains an array of the five resultant plots generated in the analysis and the respective analysis data (Figure 2). The data includes the individual damping coefficients and the correlation of determination values.

4.2 User Input Data, Calculated Data and Output Data

The user input data and calculated data are listed and described in Table 2 and Table 3 respectively.

4.2.1 User Input Data

Table 2 Program input variables

Input Variable	Symbol	Unit	Description	Use
Platform Name	-	-	Name of the platform (ship name or model name)	Recorded in the Configuration file
Condition Name	-	-	Descriptor of test condition	Forms first part of the Output Data filename
Test Number	-	-	Allocated test number in test program	Recorded in the Configuration file as reference information
Displacement	Δ	kg	Displacement of platform at time of test	Recorded in the Configuration file as reference information
Vertical Centre of Gravity	KG	m	Vertical height of the platform's centre of gravity relative to the keel	Forms second part of Output Data filename
Transverse Metacentre	KM_T	m	Vertical height of the platform's metacentre relative to the keel when in the upright (at rest) condition	Used to calculate the Inertia Coefficient and the Restoring Moment Coefficient
Beam Overall	B	m	Overall beam of the platform	Recorded in the Configuration file as reference information
Draft Amidships	T_{MS}	m	Draft amidships	Recorded in the Configuration file as reference information
Trim	τ	deg	The platform's trim (+ve trim by the stern)	Recorded in the Configuration file as reference information
Roll Amplitude (discretized data)	φ	deg	Roll amplitude of the platform	Recorded in the Configuration file The baseline data for comparison against Program simulated roll responses
Time (discretized data)	T	sec	Time variable	Recorded in the Configuration file The baseline data for comparison against Program simulated roll responses

4.2.2 Calculated Data

Table 3 Program calculated variables

Input Variable	Symbol	Unit	Description	Use
Average Roll Period	T_{AVE}	sec	Platform's roll period determined from a series of consecutive roll cycles	Used to determine Average Roll Frequency and the virtual roll gyradius
Average Roll Frequency	ω_{AVE}	rad/sec	Platform's roll frequency determined from average roll period	Used to determine the virtual roll gyradius
Virtual Roll Gyradius	k'_{xx}	m	Platform's roll gyradius accounting for its mass distribution and hydrodynamic added mass	Used to calculate the Inertia Moment Coefficient
Inertia Moment Coefficient	I'_{xx}	kg-m^2	Platform's mass moment of inertia that accounts for hydrodynamic added mass	Used as an initial condition / input parameter in the simulation algorithm
Restoring Moment Coefficient	C_{xx}	N-m	Platform's restoring moment calculated from the displacement and metacentric	Used as an initial condition / input parameter in the simulation algorithm
Transverse Metacentric Height	GM_T	m	Vertical distance between the platform's vertical centre of gravity and transverse metacentre when in the upright (at rest) condition	Used to calculate the Restoring Moment Coefficient
Linear Damping Coefficient	b^{lin}	N-m-sec	Damping coefficient term associated with linear damping effects	Intended for future use in ship motion simulation and prediction software
Quadratic Damping Coefficient	b^{qua}	N-m-sec^2	Damping coefficient term associated with non-linear damping effects	Intended for future use in ship motion simulation and prediction software
Cubic Damping Coefficient	b^{cub}	N-m-sec^3	Damping coefficient term associated with non-linear damping effects	Intended for future use in ship motion simulation and prediction software

4.2.3 Output Data

There are two forms of output data. The first is a MATLAB figure that consists of an array of five plots. Each plot presents two sets of roll response data. The red line is the test data selected by the user. The black line is the simulated response generated by the Program based on the user input data. Each of the plots corresponds to one of the roll damping model formulations listed in Section 3.2. The calculated damping coefficient data is presented above the corresponding plot. In addition to this, the R^2 coefficient is presented above the plot to indicate the correlation of the simulated data to the test data. An example is shown in Figure 2.

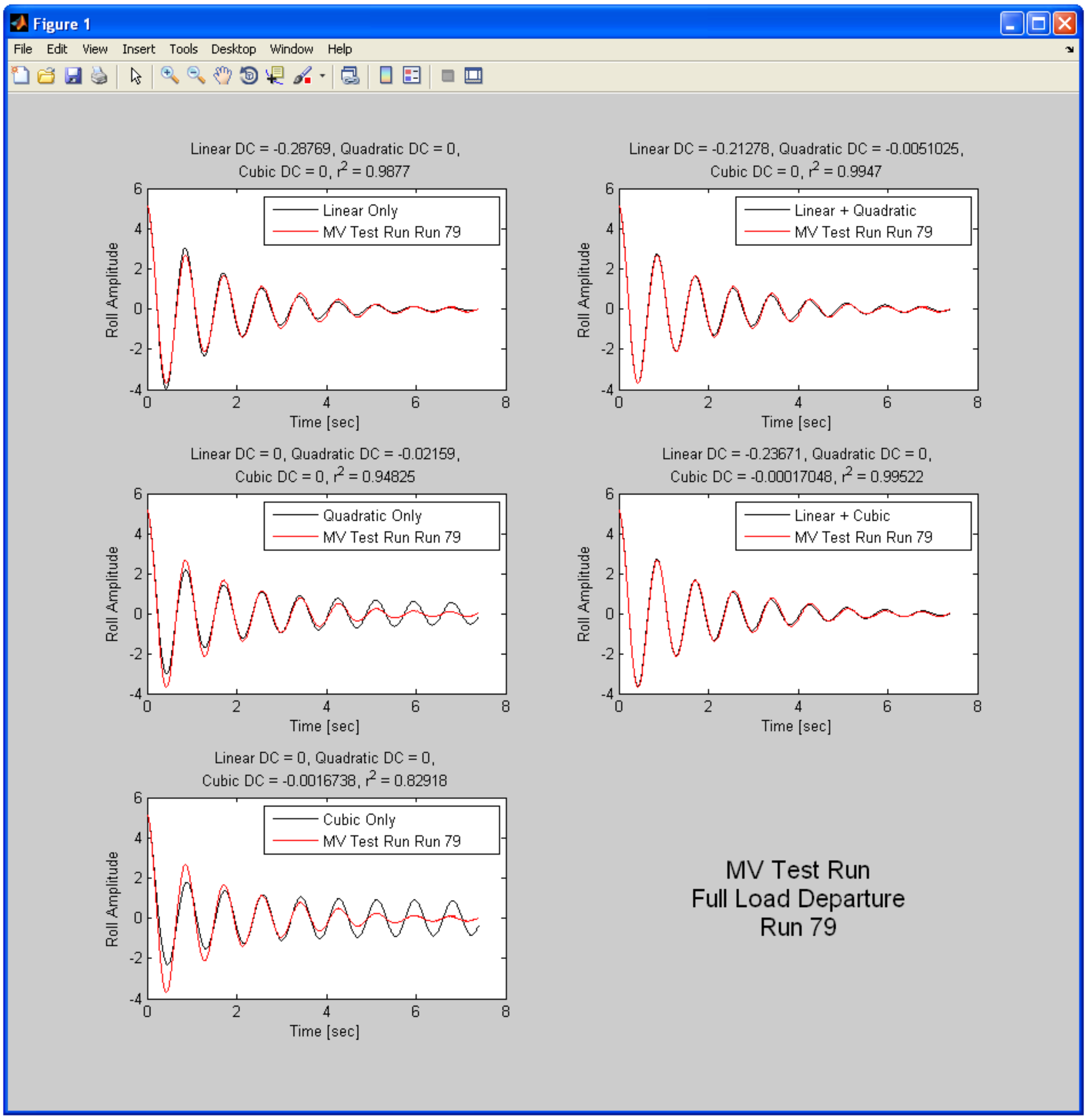

Figure 2 Example figure: Results output data indicating correlation between the simulated and test data sets, damping coefficient values and a visual representation of the simulated and test data sets

The second output is an Excel Workbook file (*.xls) with a file name of the following format: [Platform Name] Run_[Test Number].xls. The Workbook contains four Worksheets. The first Worksheet (*Variables List*) lists the Input Variables entered by the user (Table 2) and the Calculated Variables determined by the Program (Table 3). The second Worksheet (*Coefficients*) contains the damping coefficients and R^2 coefficients for each of the roll damping model formulations. The third Worksheet (*Roll vs Time*) contains the roll amplitude versus time response of the user input test data and the simulation outputs of the five different damping models. These data are set beside one another for further comparison, should it be desired. The fourth Worksheet (*Peak Periods*) presents the list of the local extrema (maximum and minimum roll amplitude) that occur in the experimental roll decay test data and the corresponding roll period measured between the successive roll cycles.

4.3 Application of Results

As described in the previous sections, the Program provides a number of data outputs. However, the two principal outputs are:

1. An evaluation of how well each of the five different roll damping formulations can simulate the roll decay test data. The evaluation is quantified using the coefficient of determination (R^2).
2. The linear and non-linear damping coefficient values for each of the five different damping models.

These two outputs are intended to guide and assist the user in understanding the roll damping and roll motion characteristics of the platform under analysis. The results of the damping model evaluation informs the user on which damping formulation, if employed in a subsequent ship motion simulation, will provide the best simulated response. Following this, the damping coefficient values can be used as a direct input into a ship motion simulation tool to enable the simulation of the platform under analysis.

It is important to consider that the validity of these results is largely based on the accuracy of the measured roll decay test data and the formulations used in the Program. The reference equations used in the Program are presented in Appendix A.

5. Document Summary

In order to accurately simulate the motion response of a maritime platform operating in a seaway, using modern numerical software tools, it is necessary to model the platform's roll damping characteristic. A platform's roll damping behaviour and therefore its mathematical representation are highly dependent on its hull shape and configuration. While a number of empirical methods have been developed to provide coefficient data for use in mathematical roll damping models, their scope of application is limited and they are therefore not applicable to all platform types. In the cases where a suitable empirical method does not exist, the roll damping response of a platform can be characterised by conducting a series of physical calm water roll decay tests, either at model scale or full scale. DSTO has developed the Roll Damping Characterisation Program to characterise the roll damping behaviour of a specific platform and generate a roll damping mathematical model using roll decay trials data. The Program provides the user with an insight into the roll response behaviour of the platform of interest. Furthermore, the Program provides a quantitative assessment of the linear and non-linear roll damping model formulations and furnishes a set of linear and non-linear damping coefficients for use in numerical ship motion simulation tools.

6. Step-by-Step User Guide

6.1 Comments on Installation and Operation

The RDCP executable program requires a version specific Matlab Compiler Runtime (MCR) package and Microsoft Excel to be installed on the target machine to enable the program to run. The following files can be provided by the authors when requested:

1. RDCP_v02.exe (32 bit version = 277 kB; 64 bit version = 329 kB)
2. MCRInstaller.exe (32 bit version = 351,078 kB; 64 bit version = 381,289 kB)

Copy these two files to a preferred location on the target computer and execute the MCRInstaller.exe file. This will require administrator rights. Once the MCR package has been installed the RDCP can be started. During initial software testing conducted on a 32 bit Hewlett Packard desktop personal computer the RDCP was observed to function satisfactorily, however, the processing of some commands were slow. In particular, some delays were experienced when initially executing the file (program start-up) and during the Data Analysis and Computation phase (Figure 1).

6.2 User Guide

6.2.1 Step 1: Start the Program

To start the analysis of the roll decay test data, initiate the program by double-clicking the RDCP application icon. A legal clause will appear that you must accept in order to continue to run the program. The clause reads:

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All rights reserved.

This data is provided by the copyright holders and contributors "as is" and any express or implied warranties, including, but not exclusive to, the implied warranties of merchantability and fitness for a particular purpose are disclaimed. In no event shall the Commonwealth of Australia and its officers, employees, agents and sub-contractors be liable for any direct, indirect, incidental, special, exemplary, or consequential damages (including, but not exclusive to, procurement of substitute goods or services; loss of use, data of profits; or business interruption) however caused and or theory of liability, whether in contract, strict liability, or tort (including negligence or otherwise) arising in any way out of the use of this data, even if advised of the possibility of such damage.

6.2.2 Step 2: Input Analysis Descriptors

The Test ID dialog box will appear (Figure 3). Enter the variables into the three fields. These inputs can be of any type; however, 'Platform Name' and 'Test Number' are used in the data output filename and should be written with this in mind. When complete, click the OK button to continue.

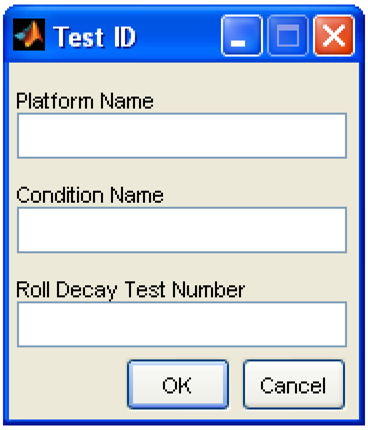


Figure 3 Test ID dialog box

6.2.3 Step 3: Nominate or Create an Analysis Configuration File

Once the Test ID data has been input you will be prompted to select whether you have a configuration file (Figure 4).

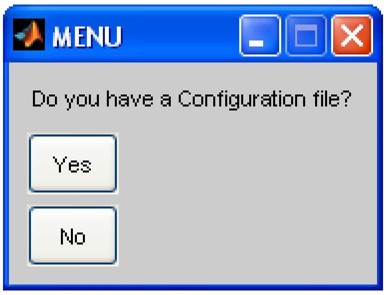


Figure 4 Configuration file prompt

The configuration file can be of two types. The first is a Microsoft Excel file in the format given below (Figure 5). The second file type that can be used as a configuration file is an output file from a previous run of the program with the same user input values. This option is included to remove the need to enter the same input data for a series of tests on the same platform for the same load conditions.

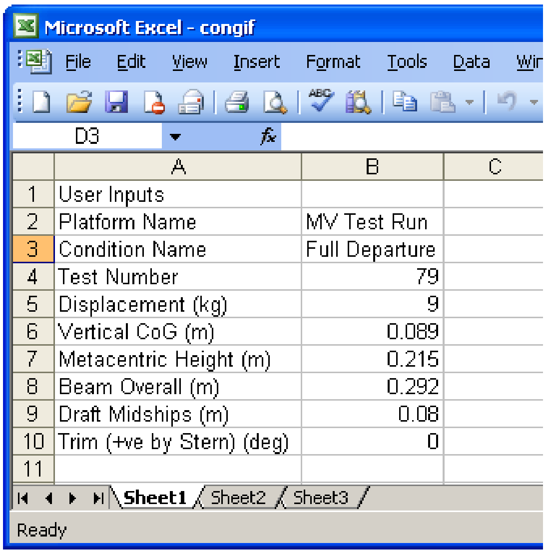


Figure 5 Configuration file format

If the user has an existing configuration file and has selected Yes at the beginning of Step 3, then the Program will prompt the user to load the configuration file (Figure 6).

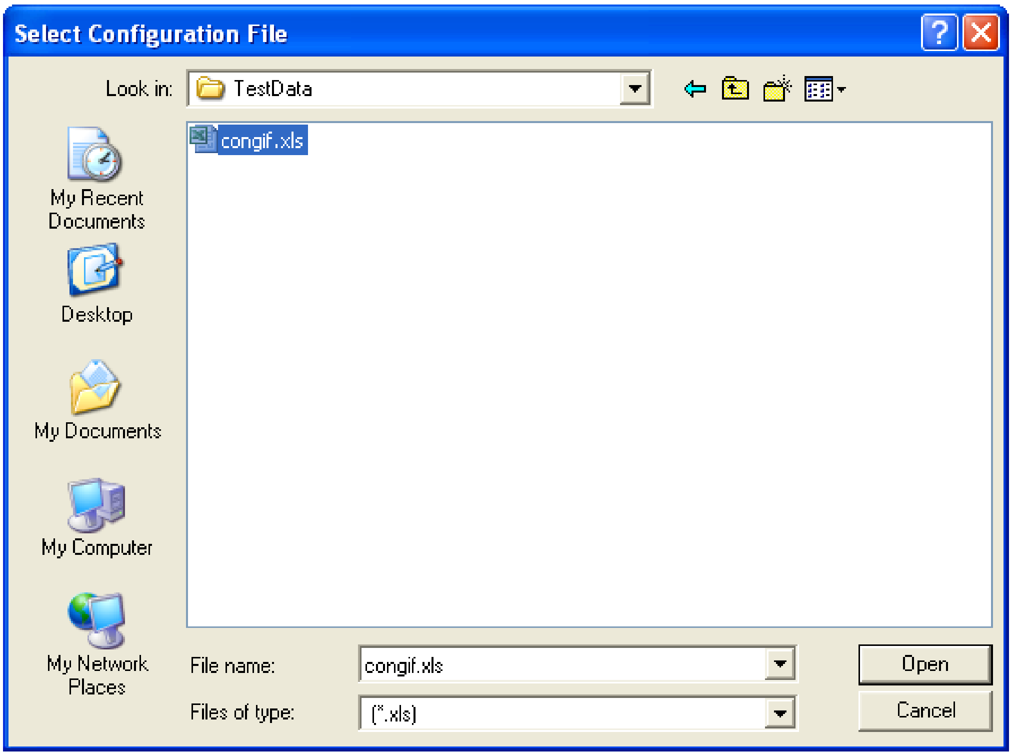


Figure 6 Loading the user nominated configuration file

If there is no configuration file or previous output file, then the program will ask the user to input the data in two dialog boxes: Test Data 1 (Figure 7) and Test Data 2 (Figure 8). All inputs must be integers.

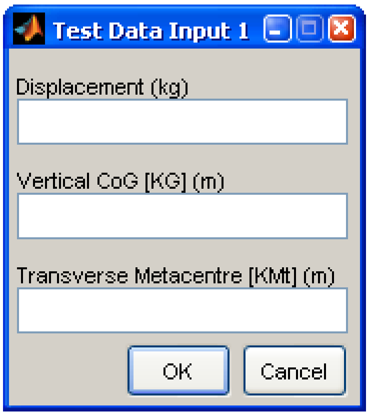


Figure 7 Configuration file Test Data Input 1 dialog box

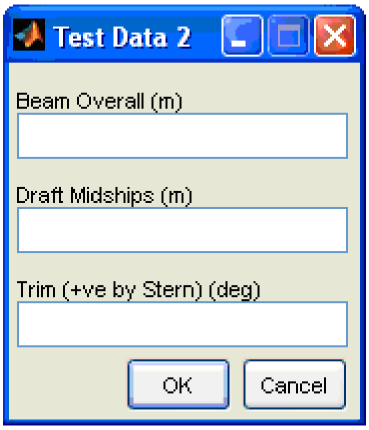


Figure 8 Configuration file Test Data Input 2 dialog box

Once these inputs have been given the user may save the data as a configuration file. This file will be saved to the same folder as the roll decay test data.

On completing the configuration file data input the user is prompted to save the file (Figure 9). If the user wishes to save the configuration file for future use or as a data analysis record, then select Yes and enter the filename at the prompt. The configuration file will be saved in the same location as the test data file selected in Step 4.

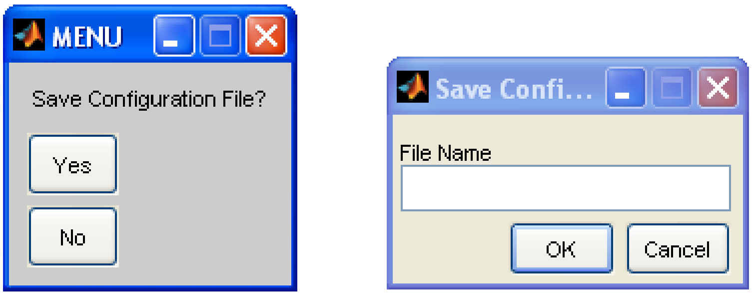
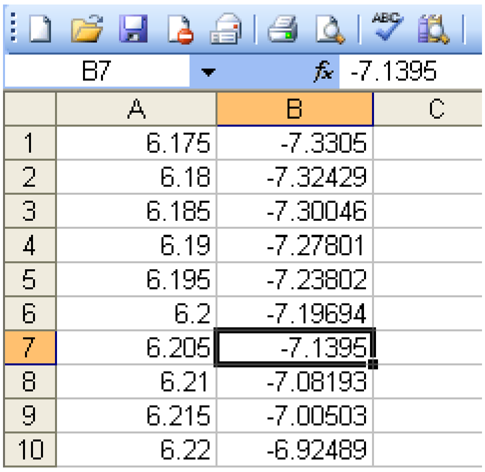


Figure 9 Save configuration file dialog boxes

6.2.4 Step 4: Load Test Motion Data

The next step is to read in the experimental data that is to be analysed. This data must be in the form of a Microsoft Excel spreadsheet with the data on the first sheet and beginning in cell A1. Column A data is the time-stamp and Column B data is the roll angle. The time stamp must be in seconds; however, the initial time does not have to equal zero. The angle can be either radians or degrees. The output file will use the same units as the input file. Both columns must start at the first row. An example is shown in Figure 10.


B7 fx -7.1395

	A	B	C
1	6.175	-7.3305	
2	6.18	-7.32429	
3	6.185	-7.30046	
4	6.19	-7.27801	
5	6.195	-7.23802	
6	6.2	-7.19694	
7	6.205	-7.1395	
8	6.21	-7.08193	
9	6.215	-7.00503	
10	6.22	-6.92489	

Figure 10 Sample roll decay test data file format (Microsoft Excel Spreadsheet)

The user will be prompted to load the roll decay test data file from a location that can be accessed from the computer (Figure 11).

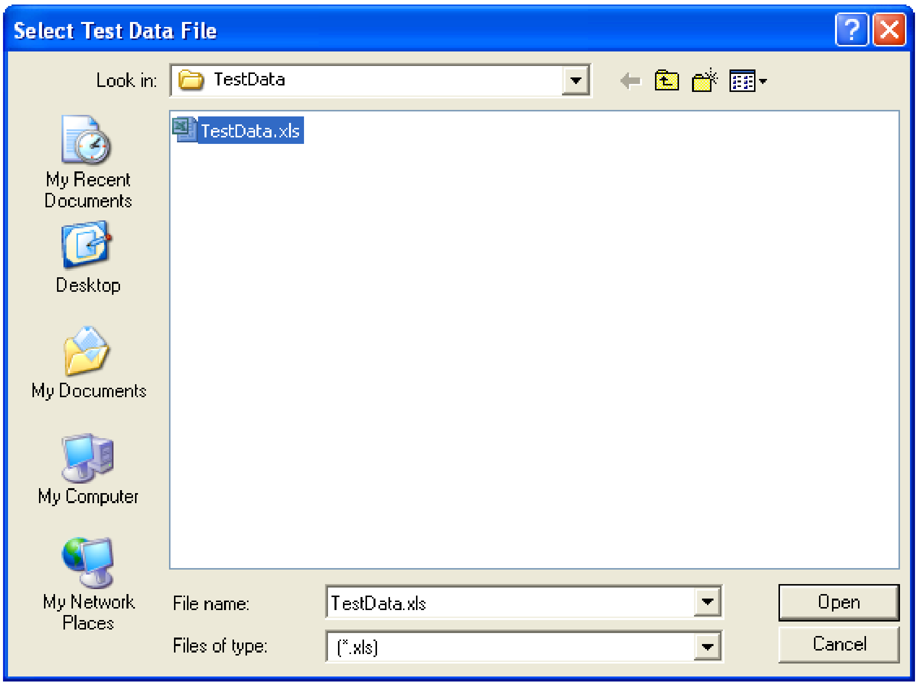


Figure 11 Loading the user nominated roll decay test data source file

6.2.5 Step 5: Select Motion Data

Once the test data file has been loaded the program will prompt the user to verify the data set to be used for the analysis. This is done using two windows: a figure window (Figure 12) and a dialogue box. The figure window displays the test data file that was read in. An example is shown in Figure 12.

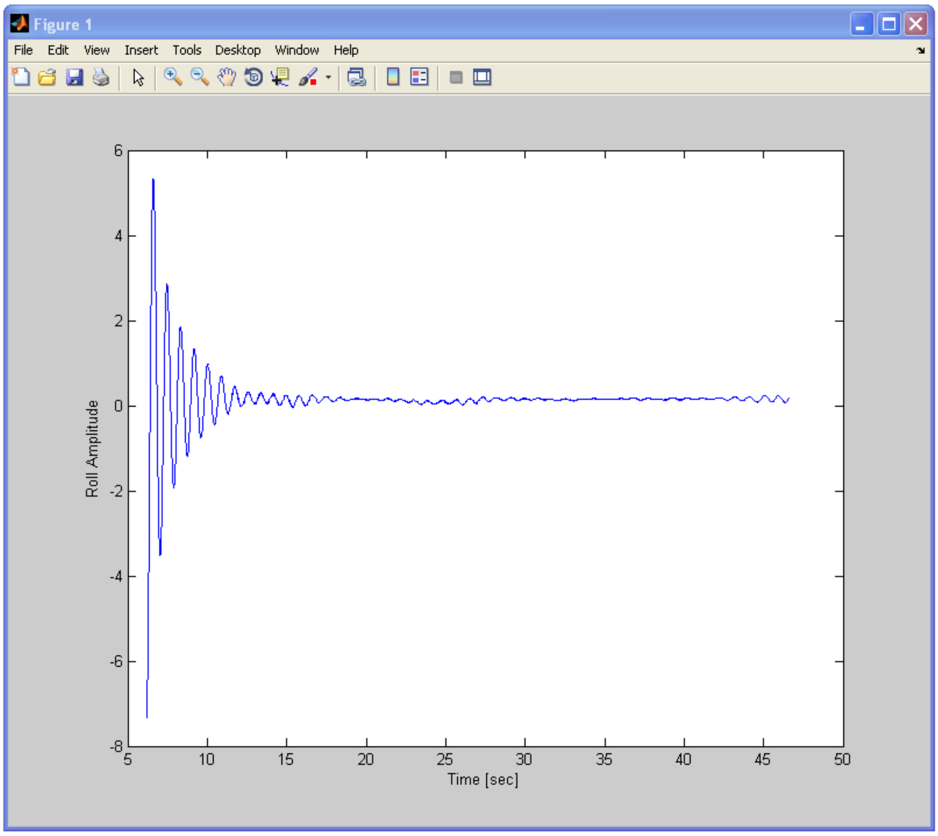


Figure 12 Roll decay test data read in from user nominated source file

The second window is the interactive MENU dialogue box. This window has three options as shown in Figure 13.

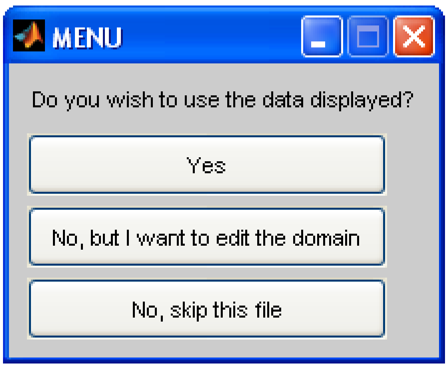


Figure 13 Test data selection dialogue box

The user is prompted to select one of the following options:

1. 'Yes, begin the analysis'
2. 'No, but I want to edit the domain'
3. 'No, skip this file'

If the data displayed is deemed acceptable for analysis then select the first option (*Yes, begin the analysis*) and the analysis of the displayed data will begin. By selecting option 2 (*No, but I want to edit the domain*) to edit the domain, a separate dialogue box will open. In this dialogue box the user can edit the data domain they wish to use (Figure 14). If the user selects option 3 (*No, skip this file*) then this will discard the data and take the user to Step 8.

If, as shown in the example data in Figure 12, the domain is not appropriate for the analysis (in this instance due to the extensive tail end of low amplitude oscillations and possible interference from reflected waves) then the second option (*No, but I want to edit the domain*) is selected. To edit the data domain the user must input the start and finish of the domain by entering the Start Time and End Time values that correspond to the domain start and finish points. It is suggested that the user allows a buffer of data (time) at the start of the domain for reasons given in Step 6. This process can be repeated until the user selects option 1 (*Yes, begin the analysis*) to accept the data domain and begin the analysis.

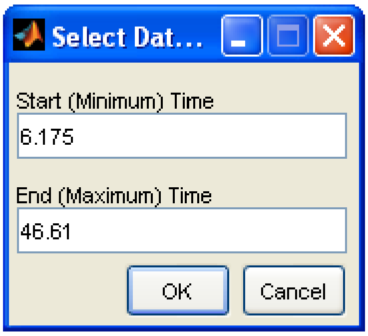


Figure 14 Data domain selection dialogue box (times shown relate to the data record in Figure 12)

The default values in the domain dialogue box will be the current domain boundaries. These can be changed to any number within the initial domain record. To accept the domain, click OK. Selecting Cancel will return the user to the previous menu without changing the domain.

6.2.6 Step 6: Select Motion Data (continued)

Once the data domain has been selected the Program will remove any offset in the data so that the mean roll angle is equal to zero. Note that the Program does not account for any drift that may be in the data. Following this adjustment the Program will search for the locations of the local minimum and maximum roll amplitudes. Finally, the data will be plotted in a figure window with the local maximum values highlighted in red and the local minimum values highlighted in green as shown in Figure 15.

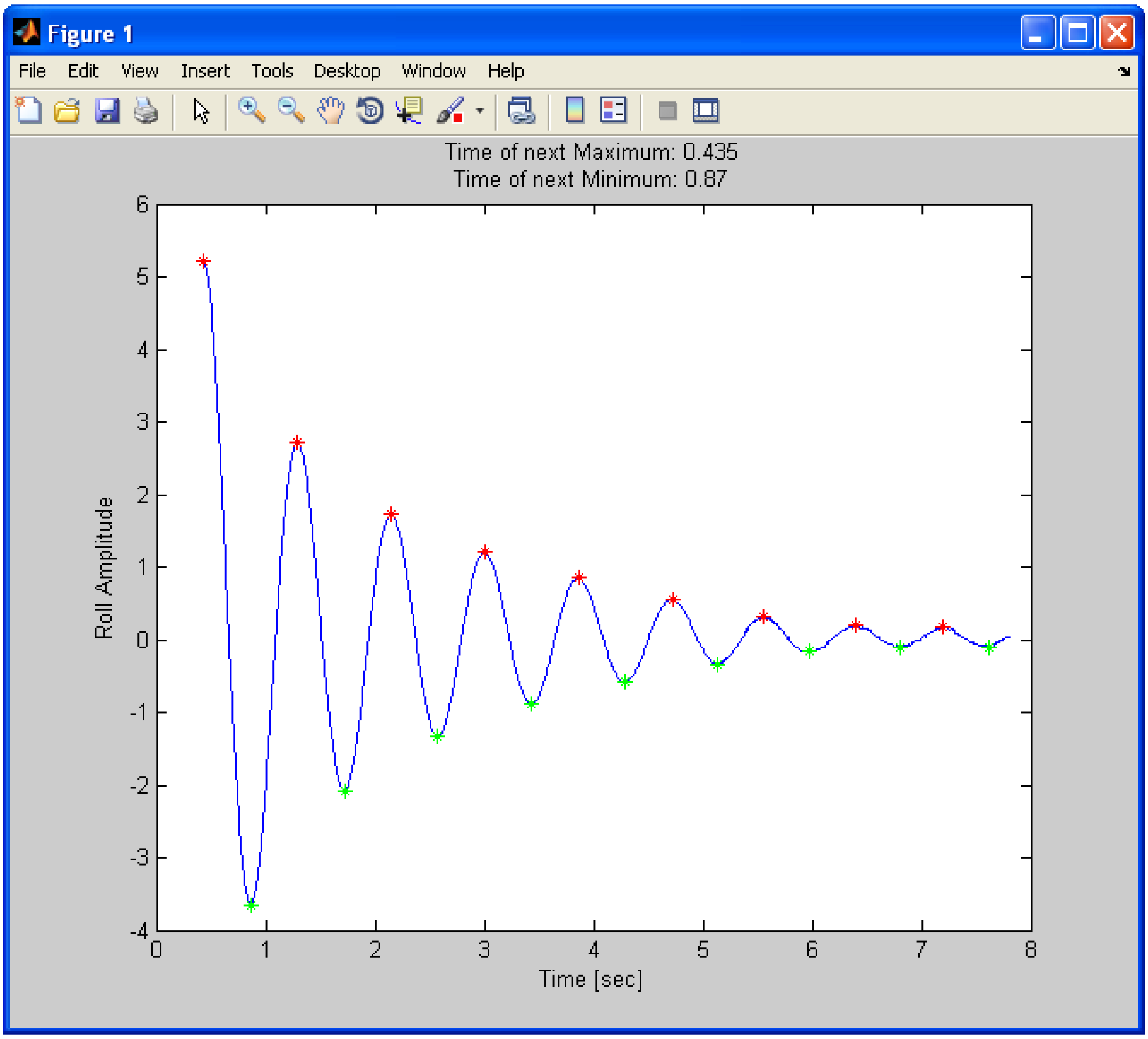


Figure 15 User nominated data domain showing the location of local maximum and minimum roll amplitudes. Any non-zero offset in the roll amplitude response has been removed

A second window offers the user the opportunity to move the location of the data domain starting point. There are three options for moving the location of the data start point in addition to the option to start the analysis or return to the original data domain, as shown in Figure 16. The five options are to use the user defined start point (*Yes, begin analysis*), the first maximum identified by the program (*No, shift start to first maximum*), or the first minimum defined by the program (*No, shift start to first minimum*). If the user deems none of these choices to be suitable, then they can opt to return to the full set of data (Step 5) and reselect the domain (*No, return to full data set*). However, once an acceptable start point has been selected the user can then select the *Yes, begin analysis* option and the data and the analysis will begin.

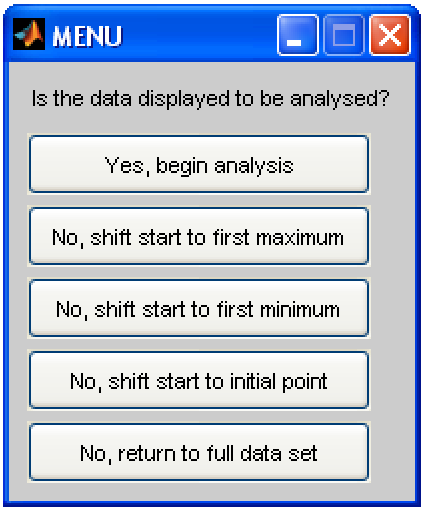


Figure 16 Data domain selection dialogue box

6.2.7 Step 7: Program Data Analysis

Having chosen to begin the analysis the Program will now execute the Data Analysis and Computation component. On concluding this process the Program will automatically create and save the two output files described in Table 1 (Page 5). These files will be saved with [Platform Name] Run-[Test Number] with the appropriate file extension. In the example shown, the files will be called "Demo Run-01.xls" and "Demo Run-01.fig". The files will be saved into the same directory as the original run data. WARNING: If a file of the same name already exists then the file will be overwritten.

At this point a figure window will appear showing the array of analysis results (Figure 17). The figure window will remain open to allow the user to inspect the analysis results.

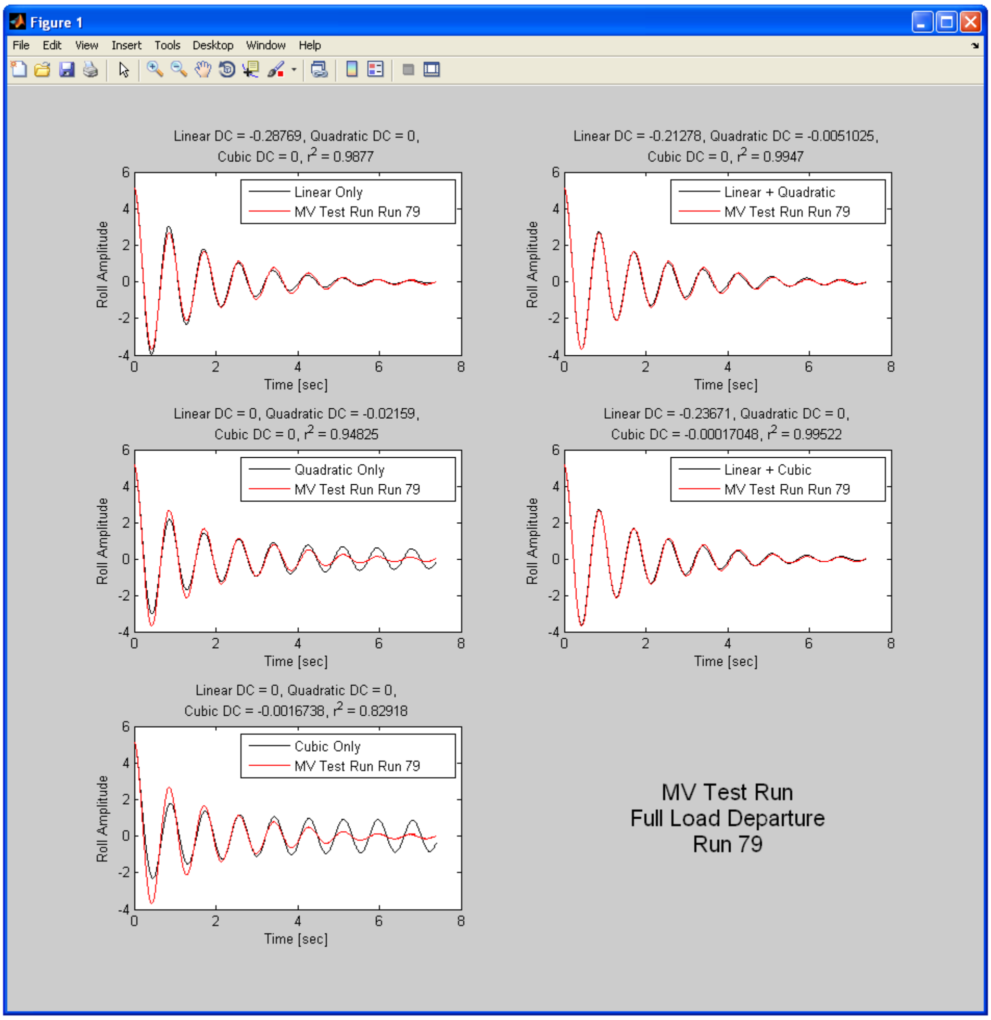


Figure 17 Results output data indicating correlation between the simulated and test data sets, damping coefficient values and a visual representation of the simulated and test data sets

At this point, the user can save a record of the graphical results (Figure 17) by selecting File | Save As.. at the top of the results figure window. A range of file formats are available.

6.2.8 Step 8: Continue or Exit

The next step is for the user to opt whether to continue analysing other test run data files or to exit the Program (Figure 18). If the user opts to continue and selects the *Start next run* option then the process will return to Step 2, otherwise the program will terminate and all the results will be found in the same directory as the inputted test data selected in Step 4.

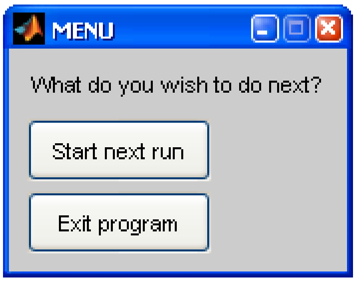


Figure 18 Continue or exit dialogue box

7. References

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Appendix A: Reference Equations

A.1. Introduction

This section presents the reference equations used in the Program's calculations. These are all standard equations and many are sourced from published textbooks as indicated.

A.1.1 Natural Roll Period

The average roll period ($T_{\phi\,Ave}$) is calculated using Equation 2 in combination with the user selected roll decay test data record. An example roll decay data record is shown in Figure A1. The average roll period is accepted as the natural roll period of the platform (T_ϕ). The natural roll frequency (ω_ϕ) is calculated from the average roll period using the standard relationship between period and circular frequency.

$$T_{\phi\,Ave} = \frac{1}{n}\sum_{i=1}^{i=n} T_i \qquad \text{Equation 2}$$

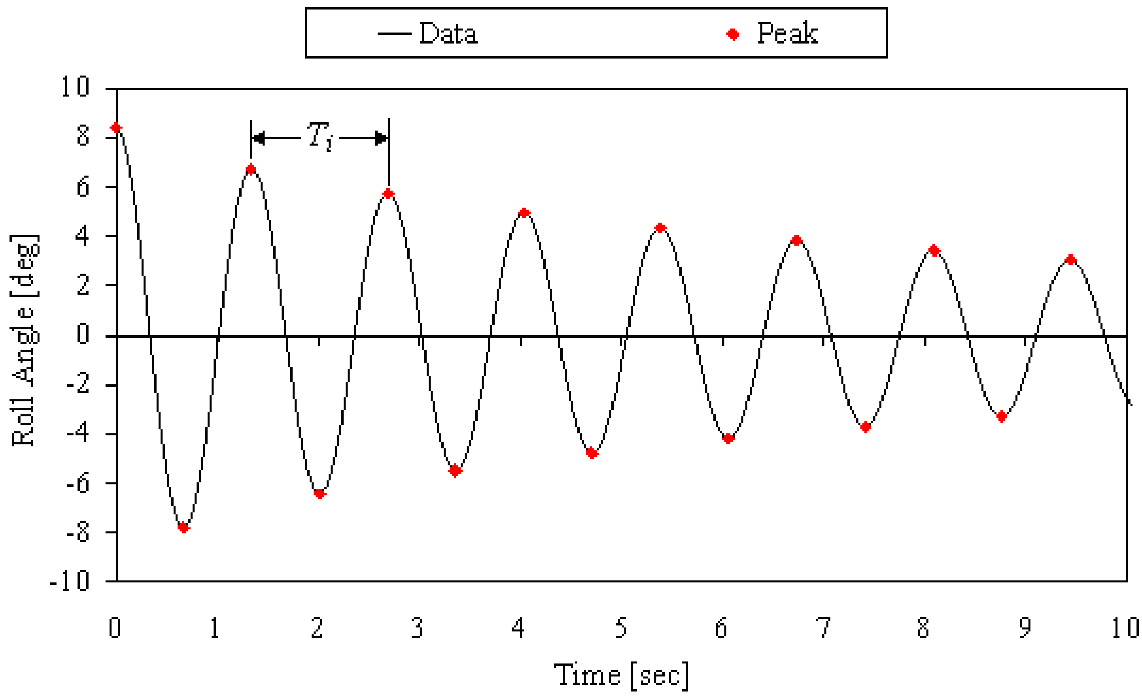

Figure A1 Example roll decay data record

A.1.2 Virtual Roll Gyradius

The virtual roll gyradius (k'_{xx}) is calculated using Equation 3 [5]. Since the natural roll period has been determined from the in-water roll decay test the virtual roll gyradius includes the effects of the hydrodynamic added mass.

$$k'_{xx} = \sqrt{\frac{g \cdot GM_T}{\omega_\phi^2}} \qquad \text{Equation 3}$$

A.1.3 Roll Inertia Moment Coefficient

The roll inertia moment coefficient (I'_{xx}) is calculated using Equation 4 in combination with the virtual roll gyradius [5].

$$I'_{xx} = \Delta \cdot (k'_{xx})^2 \qquad \text{Equation 4}$$

A.1.4 Roll Restoring Moment Coefficient

The roll restoring moment coefficient (C_{xx}) is calculated using Equation 5 where the metacentric height (GM_T) is calculated using the standard formulation and the user input transverse metacentric radius (KM_T) and vertical centre of gravity (KG) [5].

$$C_{xx} = g \cdot \Delta \cdot GM_T \qquad \text{Equation 5}$$

A.1.5 Calm Water Roll Equation of Motion

The second order differential equation used to simulate the roll motion of a body oscillating in calm water is shown in Equation 6 [6]. As previously discussed, the Program uses a standard MATLAB optimization method to solve the equation for the unknown damping coefficient terms.

$$I'_{xx}\ddot{\phi} + \left(b_0^{lin}\dot{\phi} + b_0^{qua}\dot{\phi}\left|\dot{\phi}\right| + b_0^{cub}\dot{\phi}^3 \right) + C_{xx}\phi = 0 \qquad \text{Equation 6}$$

A.1.6 Coefficient of Determination

The correlation of determination (R^2) is calculated using Equation 7 in combination with the simulation data set and the corresponding roll decay test data set [7].

$$R^2 = 1 - \frac{\sum\left(\phi_{t\exp} - \phi_{tsim}\right)^2}{\sum\left(\phi_{t\exp} - \bar{\phi}_{t\exp}\right)^2} \qquad \text{Equation 7}$$

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION **DOCUMENT CONTROL DATA**	1. DLM/CAVEAT (OF DOCUMENT)

2. TITLE Roll Damping Characterisation Program: User Guide	3. SECURITY CLASSIFICATION (FOR UNCLASSIFIED REPORTS THAT ARE LIMITED RELEASE USE (L) NEXT TO DOCUMENT CLASSIFICATION) Document (U) Title (U) Abstract (U)
4. AUTHOR(S) Edward Dawson, Murray Riding	5. CORPORATE AUTHOR DSTO Defence Science and Technology Organisation 506 Lorimer St Fishermans Bend Victoria 3207 Australia

6a. DSTO NUMBER DSTO-GD-0830	6b. AR NUMBER 016-006	6c. TYPE OF REPORT General Document	7. DOCUMENT DATE June 2014

8. FILE NUMBER 2013/1222416/1	9. TASK NUMBER NAV 07/359	10. TASK SPONSOR DMO JP2048 Phase 3 Project Manager P. Hegarty	11. NO. OF PAGES 38	12. NO. OF REFERENCES 6

13. DSTO Publications Repository http://dspace.dsto.defence.gov.au/dspace/	14. RELEASE AUTHORITY Chief, Maritime Division

15. SECONDARY RELEASE STATEMENT OF THIS DOCUMENT

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Roll Gyradius, Roll Frame Test, Ship Motion Simulation, Roll Decay

19. ABSTRACT
The Roll Damping Characterisation Program (RDCP) used by the Defence Science and Technology Organisation (DSTO) is an efficient and effective means to characterise and quantify the roll damping characteristic of a free-floating maritime platform. The program uses roll decay trial data in conjucntion with a simple numerical optimisation routine and the Fourth Order Runge-Kutta integration method to determine the platform's linear and non-linear roll damping coefficient terms. These coefficient terms are integral to conducting accurate numerical simulations of maritime platforms in support of the Australian Defence Organisation's capability acquisition programs and the Royal Australian Navy's in-theatre operations and through-life capability management. This report provides detailed operational guidance notes to support the application and use of the RDCP.